Tomography of the Inner Magnetosphere Using Numerical Field Models

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Introduction

The neutral hydrogen density distribution in the inner magnetosphere can be determined from...

- the average proton fluxes measured by the MPA instruments aboard the Los Alamos geosynchronous satellites,

- a global drift pattern calculated from numerical electric and magnetic field models, and

- the assumption that flux attenuation is caused solely by charge exchange of protons with exospheric neutrals.

Data

- The flux statistics include plasma data from three Los Alamos geosynchronous satellites.

- MPA instruments measure proton fluxes from 40 keV down to 1 eV.

- One year of spin-averaged proton fluxes merges one million measurements into a database. Figure 1 shows the fluxes of four energy channels as a function of local time and Kp index.
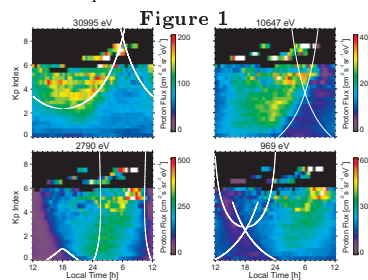
Figure 1

- The Alfvén layers (white lines in Figure 1) explain the distinct flux boundaries on the nightside.

Global Drift Pattern

- A variety of energies, locations, and Kp levels lead to a fine mesh of trajectories from the night- to the dayside.

- Magnetic field models:
  ✓ Dipole,
  ✓ McIlwain M2 (McCormac, 1972).

- Electric potential models:
  ✓ Volland-Stern (JGR, 595, 1975),
  ✓ McIlwain E5D (ASR, 187, 1986),
  ✓ Weimer 96 (GRL, 2549, 1996).

- Sample drift paths calculated from the Volland-Stern model (Figure 2).

Figure 2
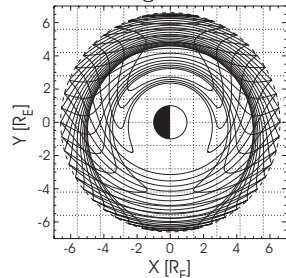
Charge Exchange

- Charge exchange with exospheric neutrals is the main loss process for ions: $H_E^+ + H \rightarrow H_E + H^+$.

- Flux decay: $f = f_0 \exp\left(-\int \alpha \, ds\right)$, loss coefficient $\alpha = \sigma v_{th} n_H$, σ is charge-exchange cross-section.

Inversion

- Discretization of flux decay leads to system of linear equations:
$$\underbrace{\sum_i \sigma_i \, v_{th,i} \, \Delta t_i}_{\mathbf{A}} \quad \underbrace{n_{H,i}}_{\vec{m}} = \underbrace{\ln\left(\frac{f_0}{f}\right)}_{\vec{d}},$$

where $\mathbf{A}$ contains the drift path, $\vec{d}$ are the flux ratios, and $\vec{m}$ are the hydrogen densities.
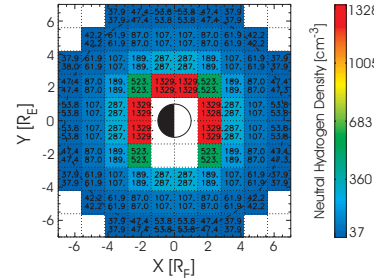
- The neutral hydrogen densities are given by:
$$\vec{m} = \left(\mathbf{A}^T \mathbf{A} + \lambda \mathbf{I}\right)^{-1} \mathbf{A}^T \vec{d},$$

where multiplication with $\mathbf{A}^T$ and the damping factor λ ensure a **square, regular matrix** required for successful inversion.

- The technique has been tested by forward modeling and subsequent inversion using a Chamberlain exosphere with Rairden 86 parameters. (Figure 3).
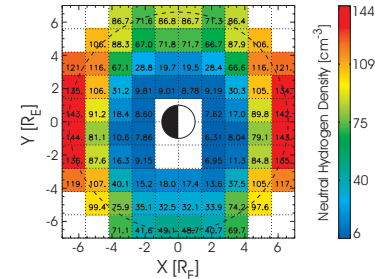
Figure 3

In Figure 3 the upper densities represent the Chamberlain model, the lower numbers show the inversion result.
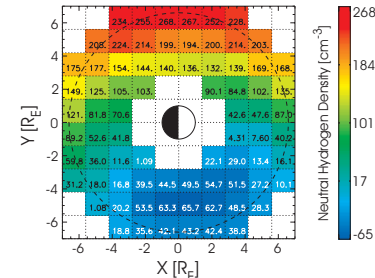
Results

- MPA data inversion using Volland-Stern/Dipole model (Figure 4) shows near-Earth densities that are much lower than Figure 3.

Figure 4

- The data inversion using the McIlwain E5D/M2 model (Figure 5) produces *negative* densities in the morning sector that can be interpreted as particle sources. (Figure 3).

Figure 5

- The Weimer/Dipole model (Figure 6) also indicates a source region in the dawn sector. The densities near the Earth are not well resolved since only few drift paths populate this region.

Figure 6
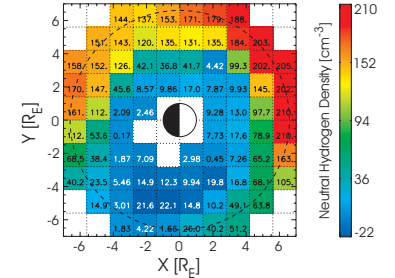
Conclusion

- Inversion algorithm was successfully tested on a testbed database obtained by forward-modeling drifts through a Chamberlain exosphere.

- MPA-data inversion shows large differences to the Chamberlain model. The differences depend on the drift pattern.

- Using the Volland-Stern/Dipole model these differences are due to lower-than-expected losses of lower-energy particles that nominally drift through the inner region.

1 keV @ 6.6 R_E

2200 LT

$Kp = 3$

- Possible implications:
  ✓ Actual hydrogen density may be lower than the Chamberlain model in the inner region predicts.
  ✓ There may be sources within the inner region.
  ✓ Drift paths don't actually penetrate as deeply as these field models predict.